Imaging Motion in Radiation research

When forming a medical image a finite amount of time must be spent on gathering the image data. There can be a number of factors affecting the time required such as waiting for the physical rotation or translation of an imaging gantry in-between imaging positions, waiting to acquire enough signal to reduce noise or delays caused by the imaging process itself which may provide contrast relating to a dynamic process. Any motion of the sample that occurs during the data acquisition period will serve to cause blurring and motion artefacts in the formed image.

In some case the time period can be quite substantial: for example in clinical magnetic resonance imaging the acquisition time period could be 30 minutes or more and the resultant volumetric image is effectively time-averaging over this period. Patient movements could induce an artefact as shown in Figure 1.

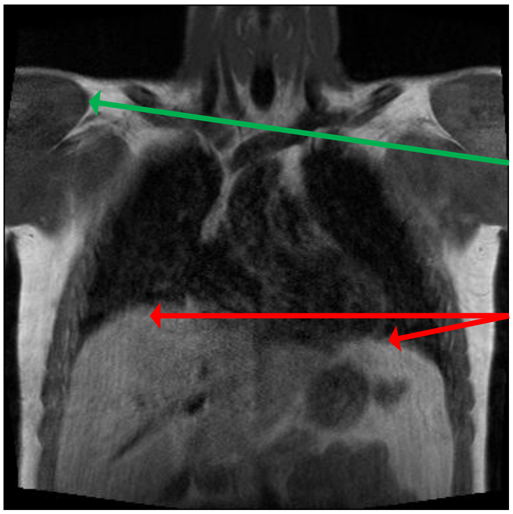

Figure 1: Imaging artefacts (edge blurring) caused by patient movement during an MRI image acquisition process are shown in red. The green line indicates the edge sharpness that could be obtained were motion is absent.

While this particular artefact (the blurred diaphragm) is obvious, this is only obvious because the motion amplitude is large and expected in this particular location. However neither of these conditions is certain and in fact they are highly unlikely to be notices in other sites.

Consider the case of a lung tumour. As part of standard clinical practice a planning X-ray CT will be acquired in order to delineate the tumour. However a CT takes too long to complete in one normal breath period. In the likely case that the tumour is moving the resulting image will be motion blurred. Hence the outlining will take place on a static image of a moving target of unknown size, shape and motion. This is an extremely challenging task. Consider Figure 2: the right section of this image is the result after the left shape is motion blurred by the path indicated by the red arrow.

Figure 2: An example of blurring (right) resulting from the vertical motion of an object (left)

The difficulty in delineating arises as the task is similar to trying to guess the object's shape and it's motion path using only the right half of Figure 2. However the solution is degenerate as objects with many different edge profiles and motion trajectories can be time-averaged to form the same resultant image. The common clinical workaround is to estimate the outline and add margins to this that attempt to account for both for the motion and outlining uncertainty. Naturally this is not an ideal situation as it involves irradiation of excessive volumes of healthy tissue thus limiting the radiation dose that can be applied; the effectiveness of treatments is thus inevitably restricted.

The problem with motion in radiotherapy is not limited to motion blurring. In many cases the image acquisition period may be fast enough to mask the underlying motion. For example human respiration (~0.25 Hz) is too slow to motion blur the diaphragm edge on a typical chest X-ray, which can be acquired in <10 ms. However the resultant image may have been acquired at any part in the motion trajectory. While it is certainly possible that the resulting image may be valuable diagnostically the same image should not be used to aim a radiation treatment beam. We thus always need to question how representative the image is of 'ground truth'.

A simple example showing the difficulty in producing representative static images of a moving system is shown in Figure 3. The figure is composed of several simulated images of a red ball bouncing on a green surface. The images are acquired at different sample and shutter rates.

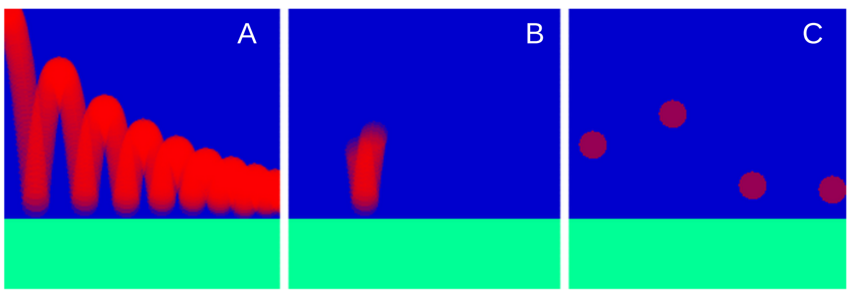

Figure 3: Imaging artefacts caused by imaging acquisition time and imaging repetition time.

The first panel (A) represents the image resulting from a very long exposure time. In this image the motion extents of the moving object are clear but the actual shape is unknown. In panel B, the result of a single, shorter exposure, taken at a random sample point is presented. It can be seen that not only are the motion extents unclear but the motion blurring prevents identification of the shape. The last panel (C) shows the case in which images are acquired very quickly at repeated but somewhat random intervals. In this case the object shape is quite clear but there is no information on the motion trajectory.

These motion issues have led to various motion compensating imaging strategies being proposed such as simply reducing or even stopping the sample's motion, imaging very quickly at predefined points in periodic systems (quasi Nyquist sampling) or even forming time-varying images. The resultant images will then be used to improve the accuracy of existing treatments or to formulate new motion-compensating treatments.

Implementing any of these strategies is time-consuming and often expensive and thus assessing the effectiveness of the various schemes beforehand is crucial. Assessment by physical phantom is very taxing as construction of a realistic moving phantom is extremely challenging. We can however turn to dynamic digital phantoms which provide an alternative cheap and effective means of researching the various new strategies.

This note was prepared by A Kavanagh and B Vojnovic in October 2011

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